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Modelling of the evolution of a droplet cloud in a turbulent flow

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The effects of droplet inertia and turbulent mixing on the droplet number density distribution in a turbulent flow field are studied. A formulation of the turbulent convective diffusion equation for the droplet number density, based on the modified Fully Lagrangian Approach, is proposed. The Fully Lagrangian Approach for the dispersed phase is extended to account for the Hessian of transformation from Eulerian to Lagrangian variables. Droplets with moderate inertia are assumed to be transported and dispersed by large scale structures of a filtered field in the Large Eddy Simulation (LES) framework. Turbulent fluctuations, not visible in the filtered solution for the droplet velocity field, induce an additional diffusion mass flux and hence additional dispersion of the droplets. The Lagrangian formulation of the transport equation for the droplet number density and the modified Fully Lagrangian Approach (FLA) make it possible to resolve the flow regions with intersecting droplet trajectories in the filtered flow field. Thus, we can cope successfully with the problems of multivalued filtered droplet velocity regions and caustic formation. The spatial derivatives for the droplet number density are calculated by projecting the FLA solution on the Eulerian mesh, resulting in a hybrid Lagrangian–Eulerian approach to the problem. The main approximations for the method are supported by the calculation of droplet mixing in an unsteady one-dimensional flow field formed by large-scale oscillations with an imposed small-scale modulation. The results of the calculations for droplet mixing in decaying homogeneous and isotropic turbulence are validated by the results of Direct Numerical Simulations (DNS) for several values of the Stokes number.

1. Introduction

The analysis of droplet dynamics and their spatial distribution in turbulent flows is important for various engineering applications, ranging from fuel injection in internal combustion engines to droplet dispersion in environmental flows (e.g. Sazhin (2014)). Inertial droplets suspended in turbulent flow fields undulate under the influence of flow fluctuations along their trajectories. The droplet velocities are controlled by both the history of the droplet motion and the spatially correlated structures of the turbulent flow field. A variety of characteristic responses of the discrete phase to the turbulent fluctuations of the carrier phase have been identified. These responses include the macroscopic scale turbulent mixing (Fung et al., 2003), de-mixing or un-mixing of particles (Fessler et al., 1994; Reeks, 2014), Random Uncorrelated Motion (RUM) (Meneguz and Reeks, 2011) and increasing settling velocity (Wang and Maxey, 1993; Maxey, 1987). In large-scale engineering and environmental applications, the behaviour of sufficiently low-inertia droplets/particles, characterised by small values of the Stokes number (the ratio of the droplet velocity relaxation time to the macro time scale) in turbulent flows, has been successfully described by the convective diffusion equation with different models for the turbulent diffusion coefficient (Fuchs, 1964; Berlyand, 1974).

Two approaches are commonly used for the analysis of turbulent droplet/particle laden flows: Eulerian–Eulerian and Eulerian–Lagrangian (see Marchioli, 2017; Simonin et al., 1993). The Eulerian–Eulerian approach gives satisfactory results for describing large-scale structures and some integral parameters of turbulent gas-particle flows in channels, jets, and boundary layers. In this approach, uniqueness of all parameters of the particulate continuum is assumed. However, the mesoscale flow regions with possible formation of local droplet accumulation zones are asso-

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